THE UPPER CRUSTAL STRUCTURE UNDER McMURDO STATION, ANTARCTICA, DEDUCED FROM BLASTS DURING NUCLEAR POWER PLANT REMOVAL

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***Abstract*:** The upper crustal structures beneath McMurdo Station, Antarctica are studied using reflected waves of blasts for dismantling the nuclear power plant in November and December of 1975. A three-seismograph network was installed near the Thiel Earth Sciences Laboratory, and reflected waves of four blasts out of many were successfully observed. As the distances between the blast points and seismographs were only 300 meters, refracted waves were not recorded. Though the velocities of seismic wave are not determined, the arrival times of clear phases of reflected waves are detected with high accuracy.

The shortest travel time of reflected waves is approximately 0.7 seconds and thickness of the first layer is 1.2 km if the P wave velocity of the layer is assumed to be 3.1 km/s. The travel time of all the well-identified latest phase is 3.95 seconds. This study suggests the presence of five layers in the upper crust.

1. Introduction

Geophysical studies on ice and rock in the McMurdo Sound region have been reported by several researchers (BELL and HEINE, 1965; BELL, 1966; MCGINNIS and JENSEN, 1971; MCGINNIS *et al.*, 1972; MCGINNIS and MONTGOMERY, 1972; ROBINSON, 1963, 1964). However the crustal structure beneath the McMurdo Station area was not studied.

During November and December of 1975, a number of explosives were detonated at McMurdo Station for removal of nuclear power plant. At this time, the present author had been observed natural microearthquakes at McMurdo Station. This microearthquake observation was carried out around the Earth Sciences Laboratory, where the observation site was very close to the drill hole of Dry Valley Drilling Project (DVDP) No. 3 (KYLE and TREVES, 1974).

Seismic waves created by the blasts were also recorded by the same seismological network. The upper crustal structure of McMurdo Station was studied using the data of reflected waves of blasts.

2. Observation

Fig. 1 shows the observation system which consists of three vertical seismographs having a pendulum period of one second. A pen-recorder with three channels was used with a paper speed of 25 cm/s.

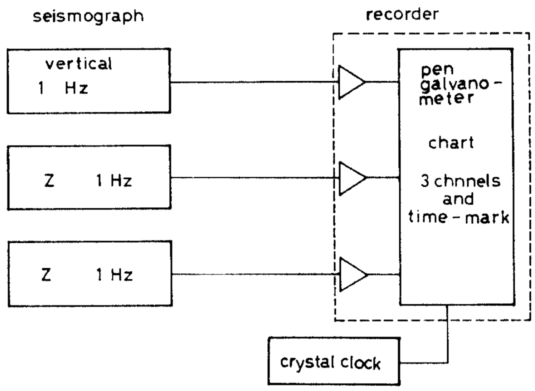

Fig. 1. The observation system for seismic wave originated by blasts.

This network was operated for checking and testing of instruments and the whole system of the observation, and not for ordinary seismic observations, so three seismographs were installed around the Earth Sciences Laboratory. Consequently large micro seisms caused mainly by traffic vibrations in the area were recorded.

The nuclear power plant was located at halfway up the Observation Hill and seismographs were installed on the north-western foot of the hill.

The left of Fig. 2 shows locations of three seismographs, the nuclear power

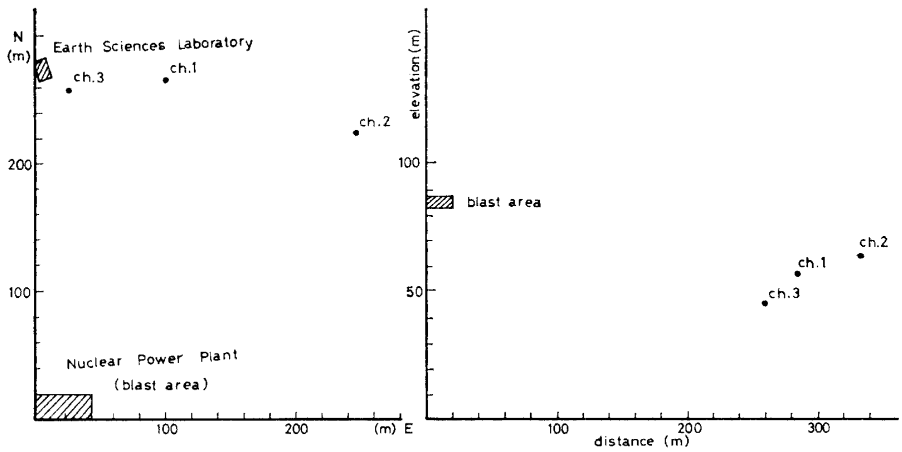

Fig. 2. The locations of the seismic observation points, the power plant and the Earth Sciences Laboratory on the ground plane (left) and projected on the vertical plane (right).

Table 1. List of blasts.

No.	Data	Charge size	Depth
1	Nov. 30, 1975	32 (kg)	6.7 (m)
2	Dec. 5, 1975	52	6.7
3	Dec. 5, 1975	35	2.1
4	Dec. 9, 1975	40	6.7

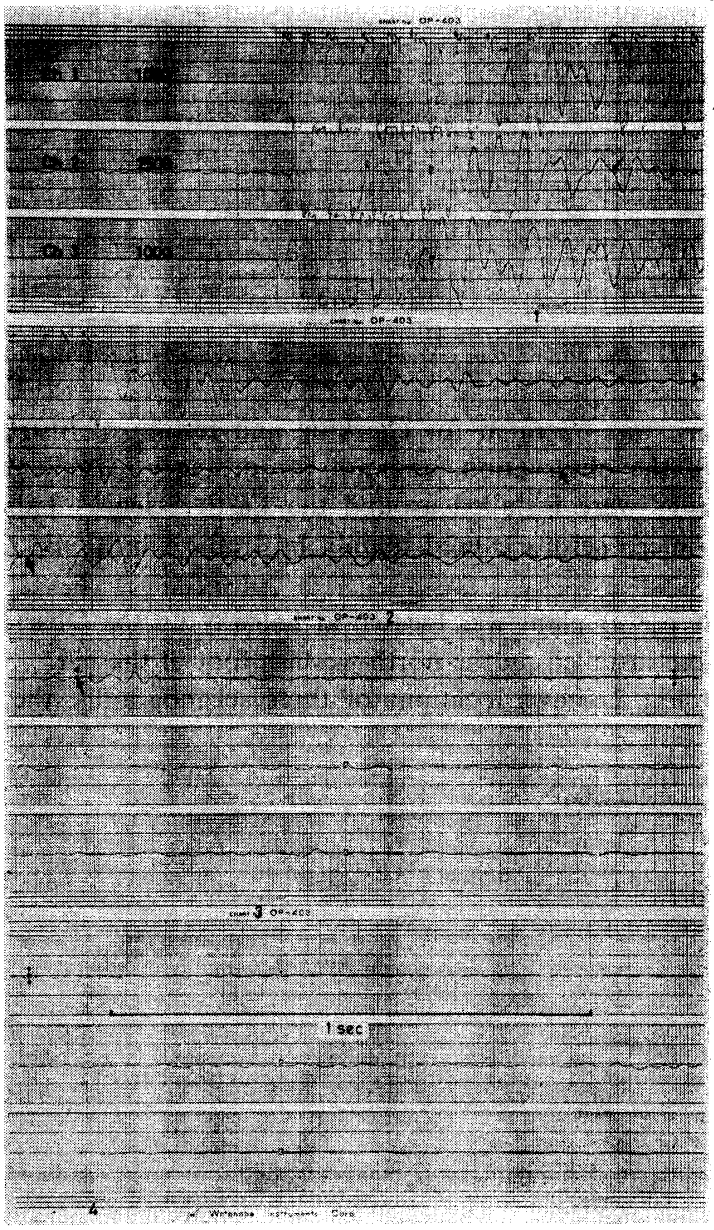

Fig. 3. Seismograms of blast No. 1. The magnifications of instruments were 1000 for channel 1 and 3, and 2500 for channel 2.

plant and the Earth Sciences Laboratory. The horizontal distances between the nuclear power plant (where is also blast points) and three seismographs versus the elevations of the nuclear power plant and seismographs are also shown in the right of Fig. 2.

The distances between the blast points and seismographs on the ground plane were around 300 m. The elevation of the blast points was 87 m and those of seismographs were between 45 and 65 m.

The positions of the blast points were from 1 m to 7 m beneath the ground surface and spread through out the plant area of about 10×10 m. The charge was from 20 kg to 50 kg.

Four blasts out of many were observed for this study and shown in Table 1.

Fig. 3 shows a seismogram of the first explosion (blast No. 1) on November 30, 1975. The charge was 32 kg and the depth of the focus was 6.7 m below the surface. The magnification of instruments was 1000 for channel 1 and 3, and 2500 for channel 2. Time signal of every one second is recorded on the bottom of the seismogram. The length of one second is shown with a solid line. Some phases of reflected waves shown with arrows on the seismogram were recorded on two or three channels, however phases recorded on only one channel were also recognized.

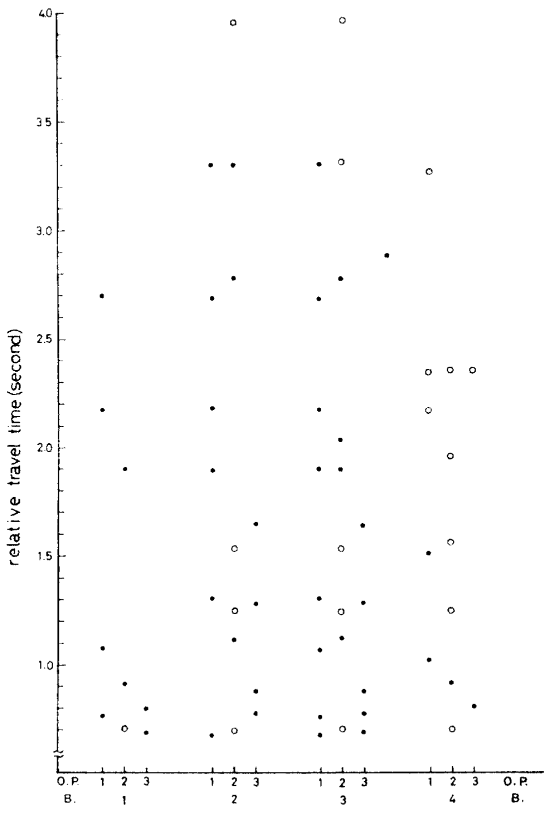

Fig. 4. Reduced travel time of clear identified phases on the records. The relative travel time was the arrival time of a phase minus that of the initial phase of channel 1.

3. Analysis

The exact time of blast was not determined in this observation, because a shot time of blast could not recorded, so a relative travel time was used in this study. The relative travel time is defined as the difference between the arrival time of a certain phase and that of the initial phase of channel 1. Relative travel times of clearly identified phases are illustrated in Fig. 4. X-axis of Fig. 4 is observation point for each blast and Y-axis is relative travel time of the reflected phases. Some phases, for example the phase of which relative travel time was around 0.7 s in Fig. 4, were recognized on almost all channels of all blasts, however some other phases were recognized on only one channel of all blasts. The phases with 2.3 s of the relative travel time was clearly observed only in the case of blast No. 4.

In Fig. 5, clear six phases are shown. The reason of selection of six phases is that they were recorded at almost all the blasts and in any of three channels. The relative travel times of these phases were about 0.7, 1.2, 1.9, 2.1, 3.2 and 3.9 seconds respectively. The amplitude of phase 5 is small however it is clearly identified in three blasts out of four. This phase is estimated to be reflected at a sharp discon-

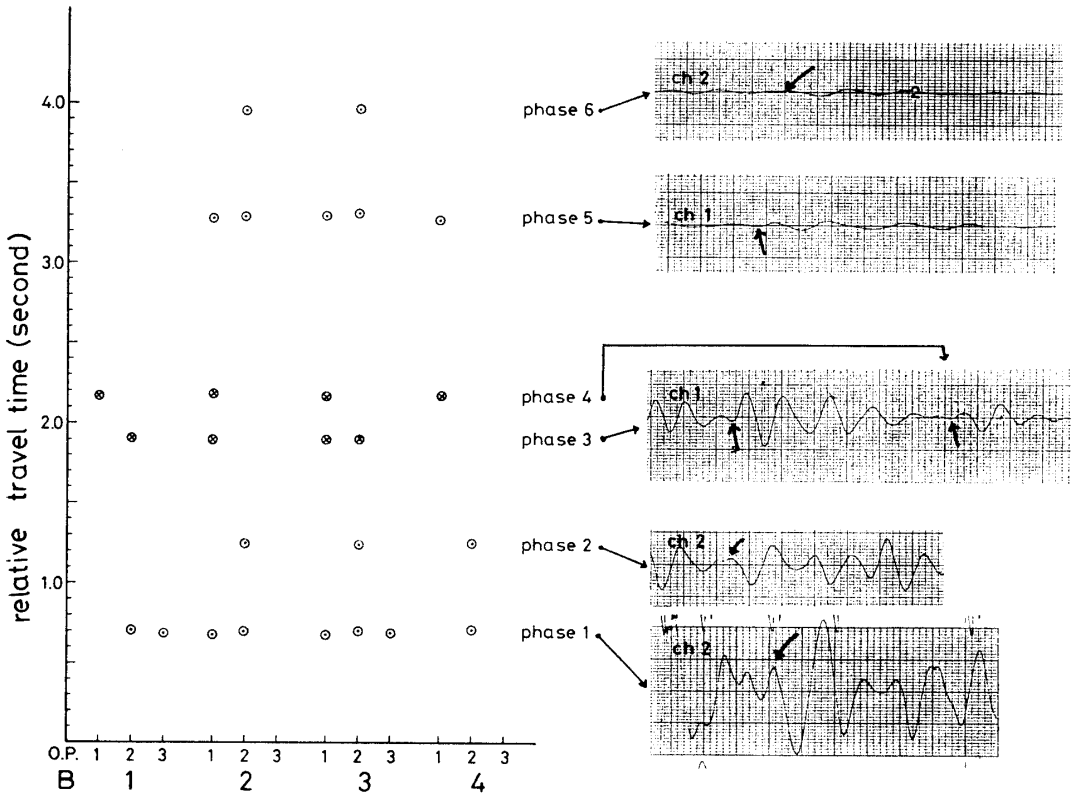

Fig. 5. Clear six phases which were recorded in any of three channel in all blasts and there reduced travel times.

tinuity. The upper crustal structure is estimated using the data obtained above and with speculation, because no refracted waves were observed and no reliable data of seismic wave velocities were obtained.

The difference between the actual travel time and the relative travel time proposed here will be discussed. The distances between blast points and observation points are less than 300 m. The velocity of P waves beneath McMurdo Station was determined to be 3.1 km/s after ROBINSON (1963). Consequently the actual travel time of the initial phase t_0 is about 0.1 s. The relative travel time is always about 0.1 s smaller than the real one, in other words, the relative travel time always has a error of 0.1 s. But 0.1 s in the relative travel time was usually an error of less than 10%. The relative travel time for the first phase is 0.7 s and this is reflected wave from a layer 1000 m in depth. Other phases are reflected from deeper layers than the first one. The real ray path of the reflected waves is shown in the left of

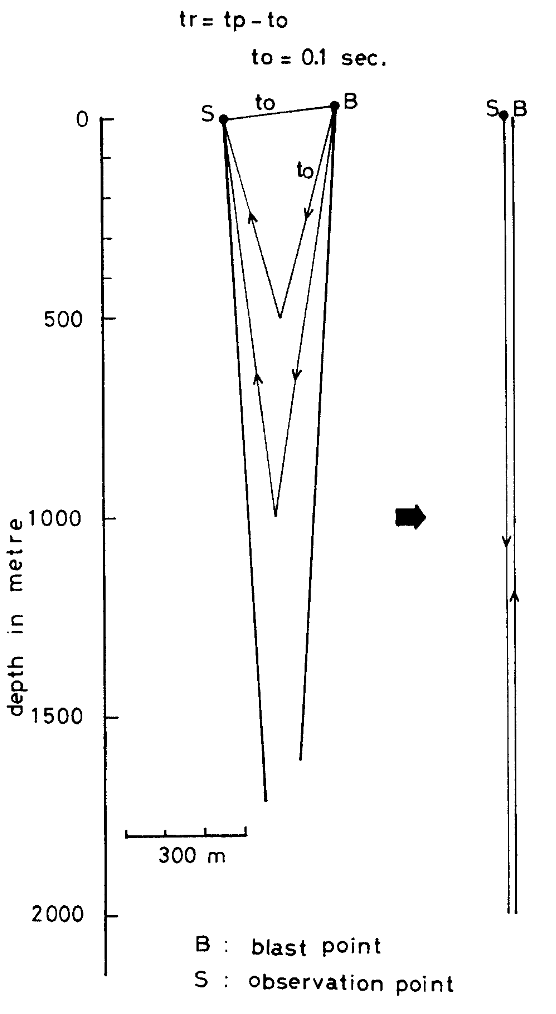

Fig. 6. The real ray path of the reflected waves (left) and the ray path used in this study (right).

Fig. 6, but all the calculations are carried out on the simplified case as shown in the right that the focus point and the observation point are nearly the same. Even in these calculations, the maximum error in the results is less than 10%.

The seismic studies beneath McMurdo Sound area have been reported by several authors (BELL, 1966; MCGINNIS *et al.*, 1972; ROBINSON, 1963). At least three clear layers are estimated. The *P* wave velocity is 3.2 km/s in the first layer, 4.8 km/s in the second layer (BELL, 1966; ROBINSON, 1963) and 5.9 km/s in the third layer (MCGINNIS *et al.*, 1972). It should, however, be remarked that several reflected waves have been observed by the present network as is shown in Fig. 5.

Instead of the surface structure reported by ROBINSON (1963), the present study has shown three different-velocity layers between 1 and 4 km as shown with asterisk in Fig. 7. Farthermore there are two alternative to the layers of which depth is more than 4 km namely case I and case II as shown in Fig. 7. The *P* wave velocity in case I is larger than that in case II, and the thickness of the corresponding layer of the *P* wave velocity in case I is thicker than that in case II. The velocities of the three layers are slightly variable, however the thickness of each layer is not so

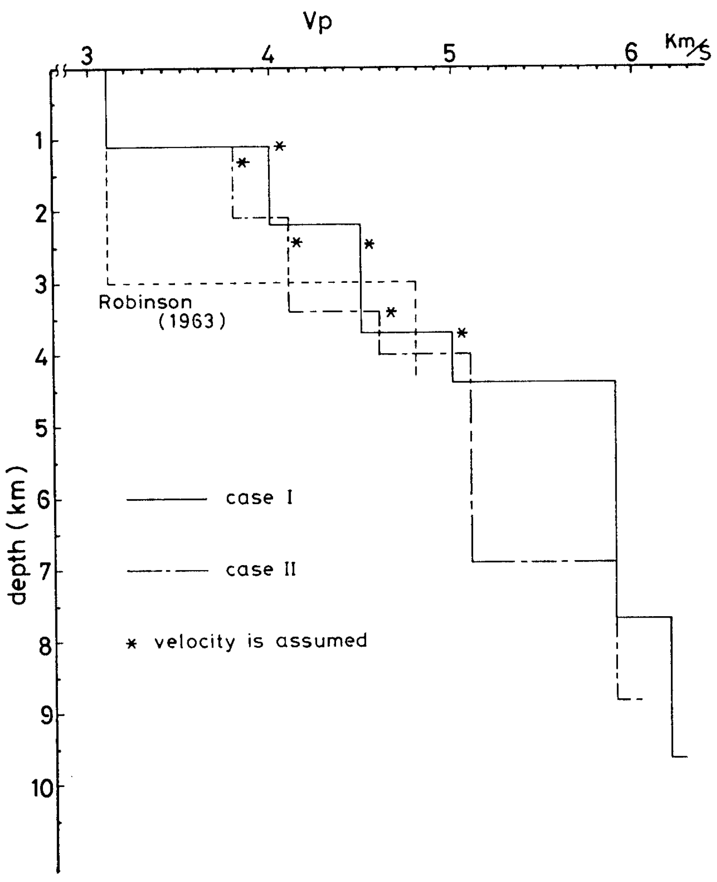

Fig. 7. The P wave velocity vs. depth estimated by this study.

variable. Phase 5 in Fig. 5 is assumed to be the reflective wave from 5.9 km/s velocity layer. The difference of the thickness to the 5.9 km/s layer estimated from case I and case II is about 1 km. If the phase 5 is assumed to be the results of reflection from the Conrad discontinuity, the depth of the Conrad discontinuity is several kilometer beneath the ground surface. From the results obtained above the crustal thickness below McMurdo Station is estimated to be around 20 km or a little thinner than 20 km.

4. Conclusion

The upper crustal structure beneath McMurdo Station, Antarctica are studied using the reflected waves. The depth of the Conrad discontinuity is estimated to be between 4 and 7 km and the normal value in Antarctica (BENTLEY and CLOUGH, 1972). From the depth of this Conrad discontinuity, the crustal thickness is estimated to be around 20 km or a little thinner than 20 km. This value is rather small in comparison with the value of Moho discontinuity in the marginal area of other continent.

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References

BELL, R. A. I. (1966): A seismic reconnaissance in the McMurdo Sound region, Antarctica. J. Glaciol., **6**, 209–221.

BELL, R. A. I. and HEINE, A. J. (1965): Seismic refraction measurements on the McMurdo Ice Shelf, Antarctica. J. Glaciol., **5**, 880–881.

BENTLEY, C. R. and CLOUGH, J. W. (1972): Antarctic subglacial structure from seismic refraction measurements. Antarctic Geology and Geophysics, ed. by R. J. ADIE. Oslo, Universitetsforlaget, 683–692.

KYLE, P. R. and TREVES, S. B. (1974): Geology of DVDP 3, Hut Point Peninsula, Ross Island, Antarctica. DVDP Bull., **3**, 13–27.

MCGINNIS, L. D. and JENSEN, T. E. (1971): Permafrost-hydrogeologic regimen in two ice-free valleys, Antarctica, from electrical depth sounding. Quat. Res., **1**, 389–409.

MCGINNIS, L. D. and MONTGOMERY, G. E. (1972): Aeromagnetic reconnaissance and geologic summary of the dry valley region. DVDP Bull., **1**, 61–90.

MCGINNIS, L. D., NAKAO, K. and CLARK, C. C. (1972): Geophysical identification of frozen and unfrozen ground, Antarctica. DVDP Bull., **1**, 30–60.

ROBINSON, E. S. (1963): Geophysical investigations in McMurdo Sound, Antarctica. J. Geophys. Res., **68**, 257–262.

ROBINSON, E. S. (1964): Correlation of magnetic anomalies with bedrock geology in the McMurdo Sound area, Antarctica. J. Geophys. Res., **69**, 4319–4326.

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